24–26 July 2003; the southwesterly winds are found parallel to the coastline (Figure 1c). This is consistent with the increase of southerly wind observed by the buoy on 22 and 25 July 2003 (Figure 1a). The increase of westerly wind during 3–5 July (Figure 1a) is also a plausible cause of the SST cooling due to upwelling away from the coast [*Pond and Pickard*, 1983].

Figure 2 shows the weekly composite sea winds measured from the NASA Quick Scatterometer (QuikScat) and SST from the Advanced Very High Resolution Radiometer (AVHRR) (shaded) for the week ending 5 July 2003. Strong northerly winds are found along the northeast Atlantic Ocean merging with the northerly winds along the northwest coast of Africa. The comparison of the sea surface wind and AVHRR SST has revealed the southward advection of cold sea water from the North Atlantic Ocean and, further westward, migration to the mid-Atlantic Ocean (Figure 2). Such southward advection of cold sea water is not found during other times, including the period 24–25 July 2003.

The surface wind direction and speed are closely related to the sea level pressure pattern. The surface weather maps (http://weather.unisys.com/) have revealed the approach of cold fronts to the mid-Atlantic coastal area during 3–5 July and 24–25 July 2003. The southwesterly winds ahead of the cold front merged with southwesterly winds at the west side of the Bermuda High over the Atlantic Ocean (Figure 2) and made the speed of the westerly or southerly wind increase. The interesting increase of westerly wind on 3 July and southerly wind speed on 22 and 25 July at the time of low SST (Figure 1a) clearly shows the influence of the surface cold front, which is rarely seen during July.

The results clearly show that the anomalous cold water event during July 2003 at the Virginia coast coincided with upwelling along the coast driven by the increasing westerly and southerly winds due to the approach of surface cold fronts, combined with the southward advection of cold sea water from the North Atlantic Ocean during 3–5 July. This cold water event had a substantial adverse effect on regional tourism and fishing.

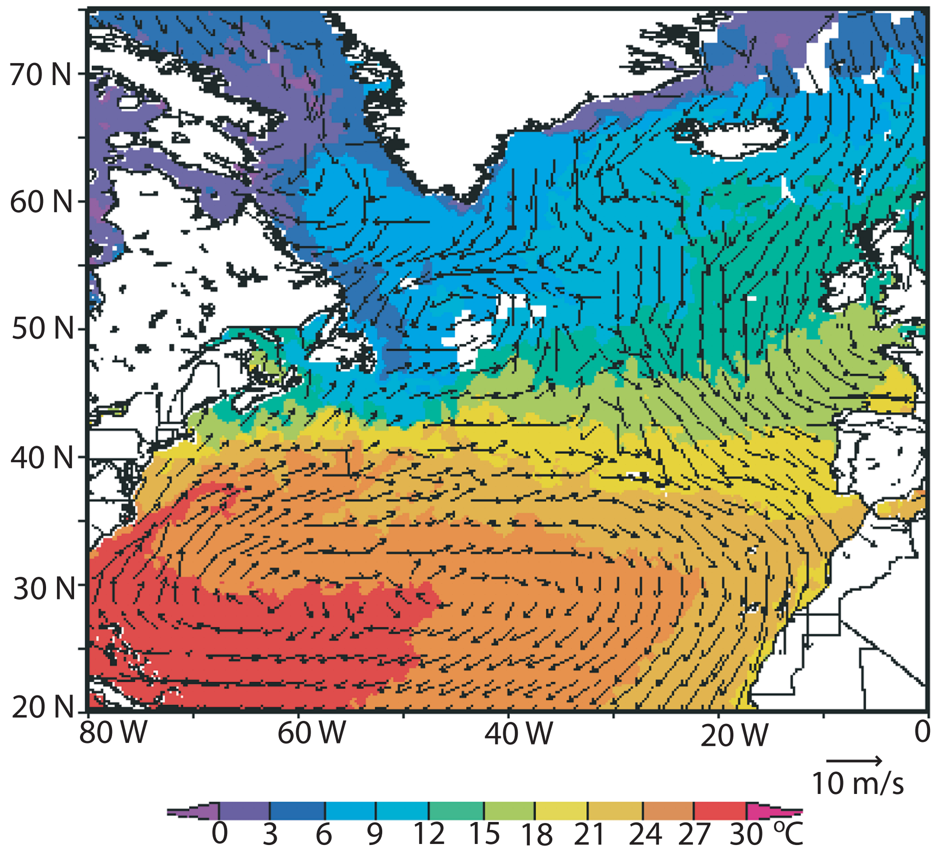


*Fig. 2. Weekly composite sea surface wind vectors and AVHRR SST (shaded) for the week ending 5 July 2003.*

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# MEETINGS

## Discussions of Arctic Climate Feedback Mechanisms

PAGE 147

The Arctic Climate Impact Assessment process (ACIA; see http://www.acia.uaf.edu/) is an international project of the Arctic Council and the International Arctic Science Committee (IASC) to evaluate and synthesize knowledge on climate variability, climate change, increased ultraviolet radiation, and their consequences.

As a part of the Norwegian work within ACIA (see http://acia.npolar.no/), an international workshop on Arctic climate feedback mechanisms was held in November 2003 at the Norwegian Polar Institute. Invited talks were presented in five sessions focused on climate programs, terrestrial systems, oceans, sea ice, and atmosphere. Poster presentations and working groups were organized for four sessions in the various scientific fields, identifying the state of knowledge and challenges, and making recommendations.

Sixty people from eight countries attended the meeting. Proceedings with extended abstracts of invited talks and working group summaries will appear in the report series of the Norwegian Polar Institute in spring 2004. The findings of this workshop provide insights that will be useful for the development of work in the near future connected to climate research in the Arctic in those fields addressed in the workshop.

### *Climate Feedback Mechanisms*

One of the aims of the ACIA process is to consider issues related to knowledge gaps and uncertainties that need to be taken into account in future research and monitoring work [*ACIA*, 2000]. This includes identifying gaps in basic knowledge and identifying fundamental data that need to be acquired to better understand climate variability and change. Uncertainties regarding the consequences of climate change lie, to some extent, in the uncertainties of feedback mechanisms, and particularly, in the depiction of these mechanisms in General Circulation Models (GCMs). These uncertainties are important and need to be considered in this context.

*Terrestrial Systems*

The terrestrial system in the Arctic, including snow, rivers, lakes, and vegetation, plays a crucial role in the global climate system through many complex interactions and feedback mechanisms. Despite numerous studies and our broad knowledge of the subsystems, knowledge gaps exist within the complex interactions among the different systems.

In hydrology, the broadest impacts of global warming on the non-glaciated terrestrial Arctic regions will result from changing permafrost structure and extent. The permafrost will become warmer and the active layer will become thicker. Snow cover in the northern hemisphere also has a large influence on the Earth's albedo and on the global radiation balance. Snow also interacts strongly with vegetation, which traps it and reduces redistribution and sublimation, leading to thicker snow that again influences vegetation and albedo. Snow cover changes will also influence the release of greenhouse gases from soil.

However, knowledge of feedbacks on larger spatial and temporal scales is lacking, owing to insufficient monitoring systems and insufficient use of holistic approaches. For the ice-covered terrestrial areas in the Arctic, several strong positive feedback mechanisms characterize glacier-climate interactions; for example, feedbacks for melt-rate/albedo, melt-rate/glacier sliding, and mass-balance/surface-elevation. Most Arctic glaciers and ice caps showed significant mass loss during the second half of the 20th century as a possible consequence of these feedbacks.

*Oceans*

Significant progress has been made in the past 10 years, both in oceanographic observations—for example, measurement of transport through the Nordic seas—and development of high-resolution models capable of simulating dynamics and anomalies of the water masses. Yet the Arctic Ocean is still very poorly known. In general, present-day GCMs cannot assess the observed changes to the thermohaline circulation because of gaps in understanding, a shortage of measurements, and insufficient modeling of fresh water export and circulation/convection forcing. Changes in stratification associated with temperature and salinity changes, atmospheric processes, and river runoff—including permafrost thaw and precipitation changes—are poorly understood. The position and dynamics of fronts and the ice edge of the marginal ice zone, which influence deep-water formation and overflows, need to be better determined. More knowledge gaps exist around factors controlling greenhouse gas release and carbon sequestration, for example, sea ice and ventilation.

Consequently, future activities will need to address the dynamics of the Arctic Ocean circulation, considering the fresh water balance, and parameterizing Arctic Ocean and Nordic seas processes in the GCMs with enhanced resolution and focus. This will allow model reconstructions of the present state in the Arctic, and improved future simulations. Complete fundamental surveys of the sea ice and ocean, along with long-term monitoring activities, have to be maintained and expanded to document and understand Arctic climate variability.

*Sea Ice*

Sea ice extent, thickness, and distribution; snow depth on ice; and energy budget and dynamics are key factors for understanding the role of the ice cover in climate change. It is well established that the ice extent is significantly decreasing. While there is evidence that the ice thickness is also decreasing, the record is not as comprehensive as that for ice extent. It is imperative that ice thickness monitoring using ship and submarine surveys, upward-looking sonars, and satellite remote sensing be continued and expanded.

Satellite and field observations indicate an increasing net energy budget of the ice. Limited information indicates a downward trend in albedo, but knowledge of large-scale changes in albedo is incomplete. Because of the ice-albedo feedback, changes in albedo are of major importance and require additional study. Albedo information is also required for advanced parameterizations in climate modeling. Snow acts as an insulator, retarding ice growth in winter, and as a reflector, reducing ice melt in summer. However, snow-on-sea-ice information is sparse. More field studies are required, as well as the development of remote sensing techniques capable of monitoring snow properties. Future work needs to include monitoring studies, as well as efforts directed at understanding the key physical processes. Interdisciplinary approaches that integrate processes in the atmosphere, ice, and ocean will be of particular value.

*Atmosphere*

Internal atmosphere evaporation processes and extent; knowledge of humidity, temperature, and condensation; and the process of polar heat transport in the Arctic are relatively well understood. A high level of understanding prevails regarding the role of the surface albedo in atmospheric processes. Knowledge gaps were identified within feedback processes relating especially to clouds and aerosols in the atmosphere, the interaction between the troposphere and stratosphere, eddy transport processes, and mechanisms controlling the development of atmospheric frontal positions on monthly to seasonal time scales. Other important knowledge gaps were identified regarding the Arctic boundary layer, where the current level of understanding is poor and expectations for sufficient modeling development are low. The investigation of so-called "extreme events" was identified as another important challenge, as even the concept itself may not be well defined. These events are often invoked when episodes of a physically defined phenomenon occur irregularly and by nature seem to be very rare. They may be defined in different ways; that is, as complex, risk-related events, threshold-defined/ irreversible events, simple statistical outliers, or events connected with the human perception of extreme or changing processes. Many events could fall into several of these categories, but the way they would and should be analyzed presumably differs.

Extreme events seldom occur, or occur with high inter-annual variability, which makes their investigation difficult. However, extreme events also require further attention, as they potentially can result in severe socio-economic and ecological problems.

In all fields, enhanced monitoring, process studies, and modeling were identified as high-priority future work. Better spatial and temporal resolution, as well as the use of modern technology, are keys to improved investigations of the Arctic; and they are indispensable for investigating nonlinear processes, extreme events, and rapid changes. Remote sensing studies will require detailed ground-truthing work to be a powerful tool for accurate monitoring. However, all working groups at the workshop also identified the need for, and importance of, integrated and interdisciplinary work, linking studies and knowledge in individual fields to a comprehensive picture.

The ACIA process may continue after the planned reports are submitted and presented this year. Thus, it is important now to begin a process to identify and illuminate the challenges and issues faced in assessing the consequences of climate change in the Arctic.

The International Workshop on Arctic Climate Feedback Mechanisms was held 17–19 November 2003 at the Polar Environmental Centre in Tromsø, Norway.

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